# Physical Properties of Particulate Matter (PM) from Heavy Duty Diesel Vehicles Operating with Advanced Emission Control Technologies

Shaohua Hu, Subhasis Biswas, Constantinos Sioutas
Department of Civil and Environmental Engineering
University of Southern California
Los Angeles, CA 90089

Jorn Herner, Williams Robert, Alberto Ayala
Research Division
California Air Resource Board
Sacramento, CA 95812

26th AAAR Annual Conference, September 25, Reno, NV

# Acknowledgements

**USC**

- Michael Geller
- Harish Phuleria
- Zhi Ning
- Vishal Verma
- Payam Pakbin
- Mohammad Arhami

**CARB**

- Ralph Rodas
- George Gatt
- Paul Rieger
- Oliver Chang
- Christine Maddox
- Keshav Sahay
- Jim Shears

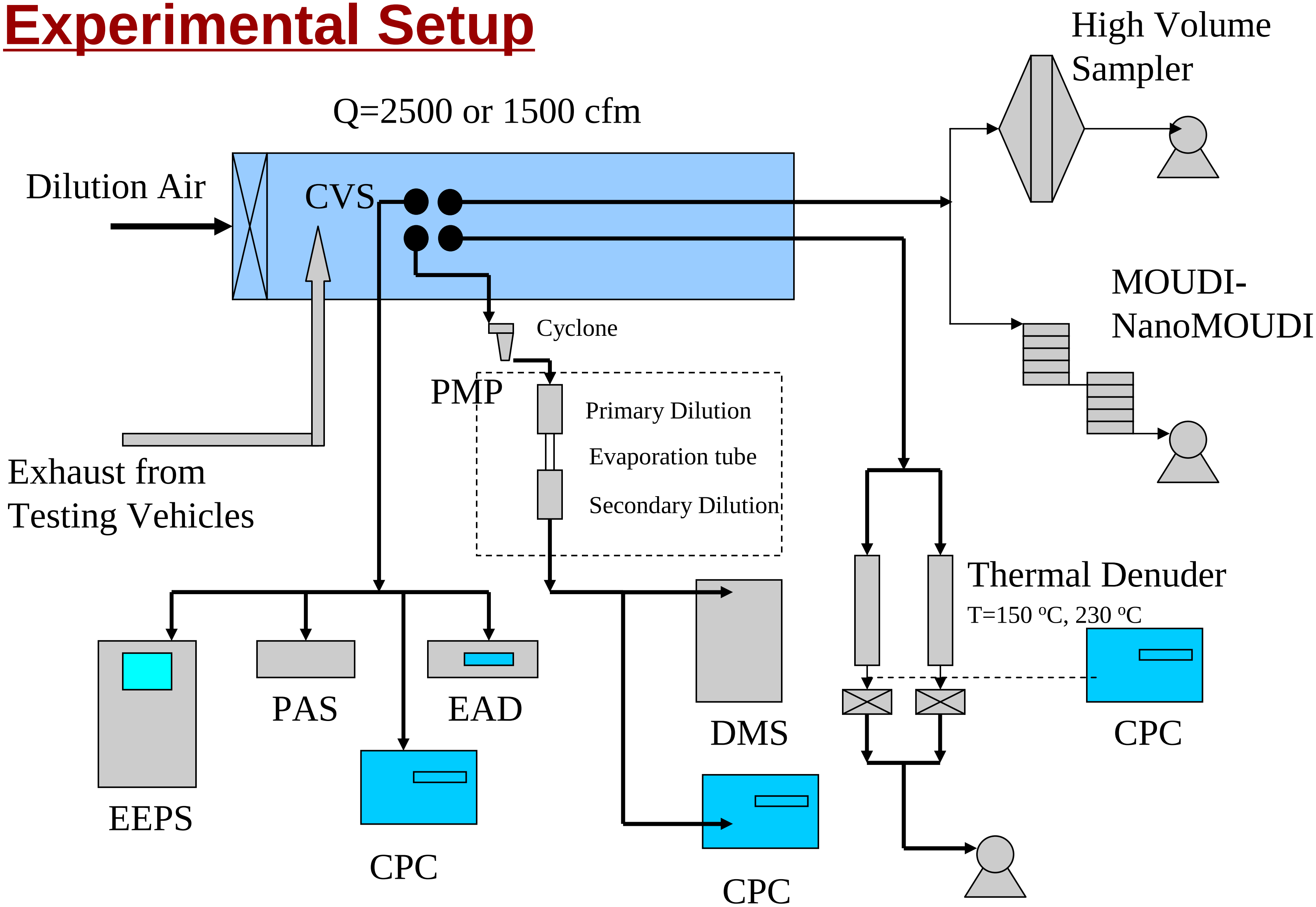
## Sponsors

- California Air Resource Board (CARB)
- California Energy Commission (CEC)
- South Coast Air Quality Management District (SCAQMD)

# Background and Motivations

- A rapidly increasing epidemiological and toxicological evidence links cardio-respiratory health effects and exposures to ultrafine particles (Peters et al., 1997; Li et al., 2002 and 2003; Xia et al., 2004)
- Emission inventories suggest that motor vehicles may be the primary emission sources of ultrafine particles to the atmosphere in urban areas (Hitchins et al., 2000; Zhu et al, 2002)
- US EPA 2007 regulation is aimed to reduce the diesel PM mass emission by ten fold from existing 0.1g/bhp-hr PM limit to 0.01g/bhp-hr in 2007 (Merrion et al., 2003)
- Newer after treatment technologies, such as SCRT, have been proposed to capture non-volatile fraction of exhaust emissions. However, volatile fraction of PM is less influenced
- This is a multiple year project to investigate the physicochemical and toxicity of the volatile fraction of emissions from newer diesel vehicles
- This presentation summarizes the physical properties of PM emissions from diesel trucks operating with selected catalysts (vanadium and zeolite) SCRT system comparing to a baseline vehicle

# Experimental Setup



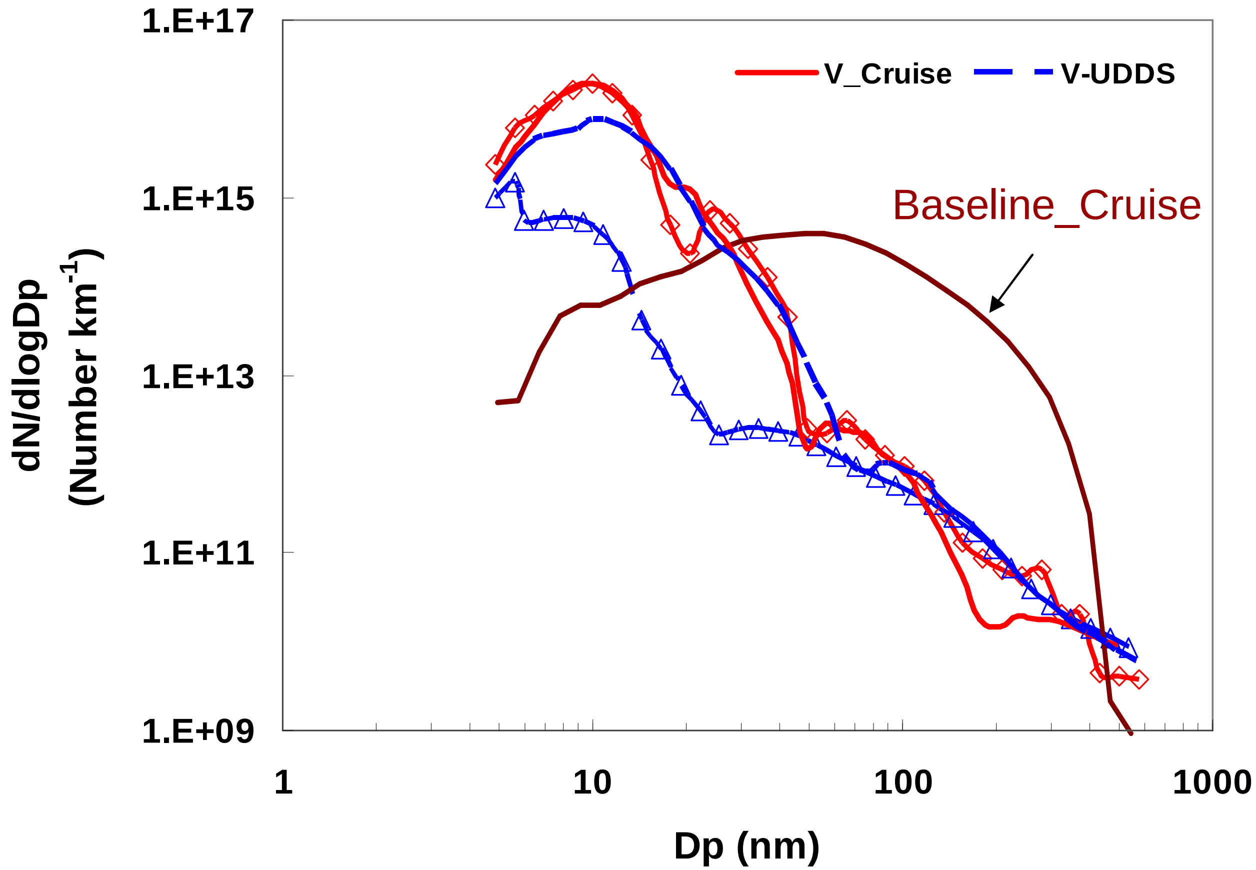
# Vehicle and Driving Cycles

- Vehicle
  - **Make \Year\ Miles\ Curb Weight (lb)\ GVWR (lb) \Tested Wt (lb)**
    - Kenworth\ 1998\ 374000\ 26,640\ 80,000\ 53,320
  - **Engine Model \ Size [L]**
    - Cummins M11, reflashed \ 11
  - After Treatments
    - Baseline: None
    - VSCRT: vanadium based SCRT
    - ZSCRT: zeolite based SCRT
- Driving cycles
  - Steady state: cruise at 50 mph
  - Transient: EPA UDDS
  - IDLE
- Fuel: ULSD

- **Other Advanced After Treatment Technologies tested**
  - **Hybrid Diesel**
  - **DPX**
  - **CRT**
  - **Horizon emission control system**

**Refer to Herner et al., for more details**

# Size Distribution

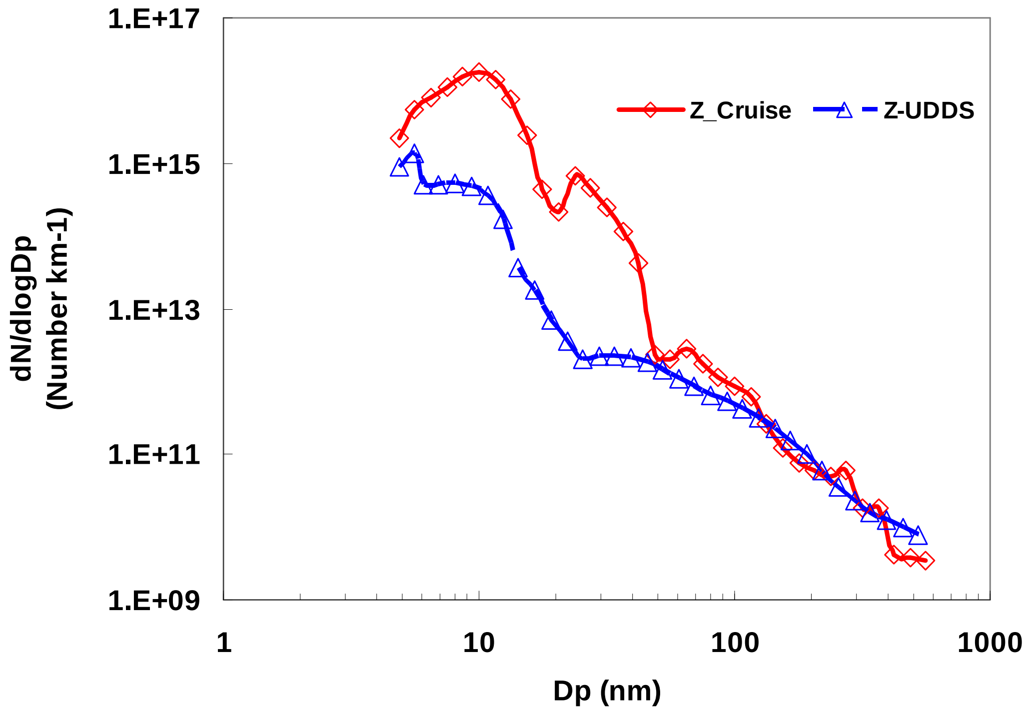


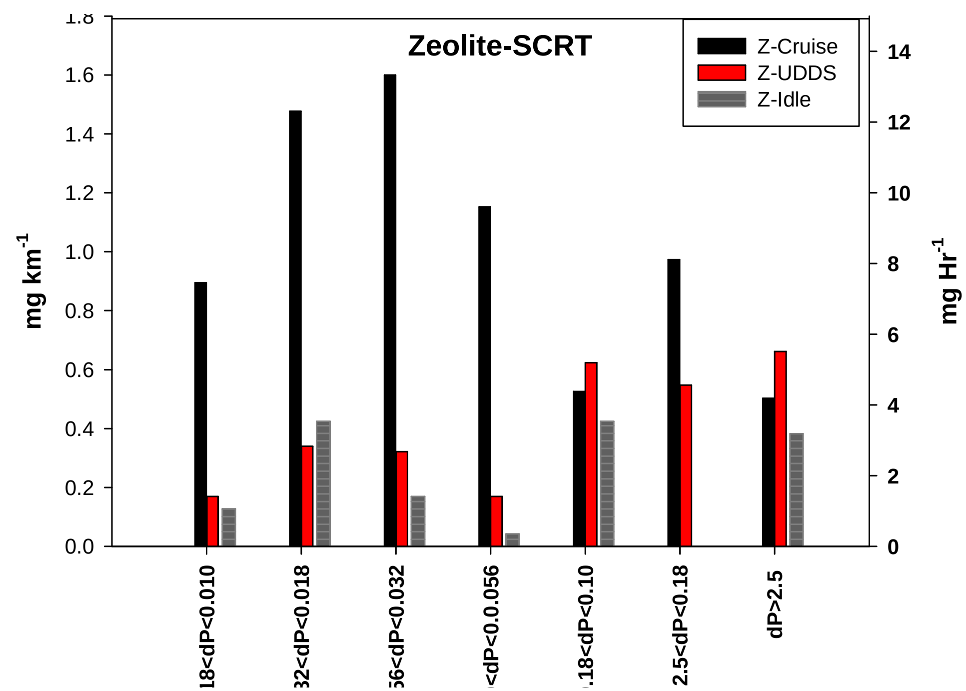

- **CVS measurements with dilution of 2500 cfm**
- **Significant nucleation mode particle formed for both SCRT systems**
- **Identical size distribution for both SCRT systems at cruise cycles**
- **Lower emission factor for Zeolite UDDS cycle**

University of Southern California

# Size Distribution

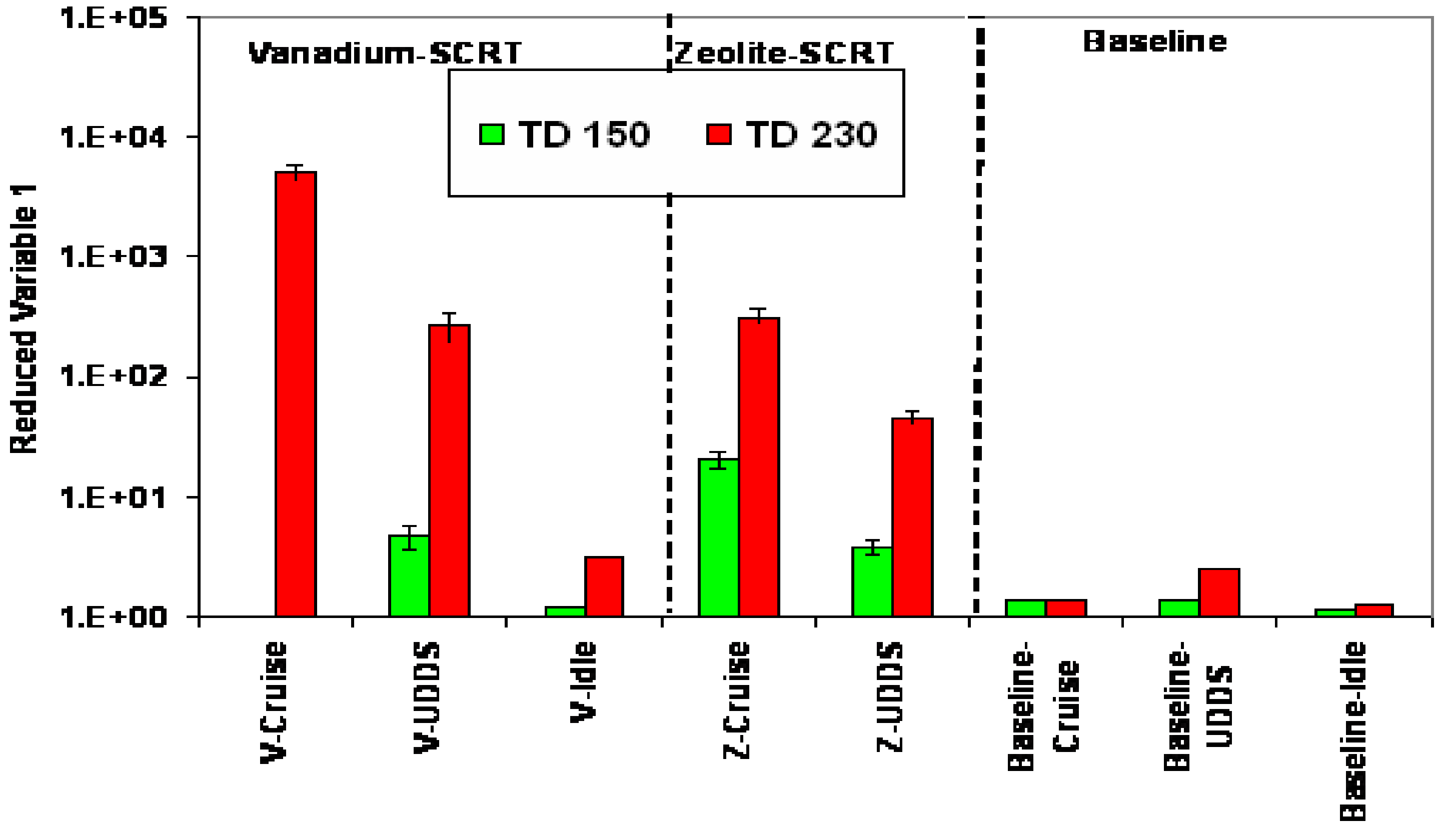
- Mass size distribution measured by nanoMOUDI in 7 size channels
- Agrees with number size distributions (shown for Zeolite SCRT).
- Significant mass reductions (comparing to baseline)



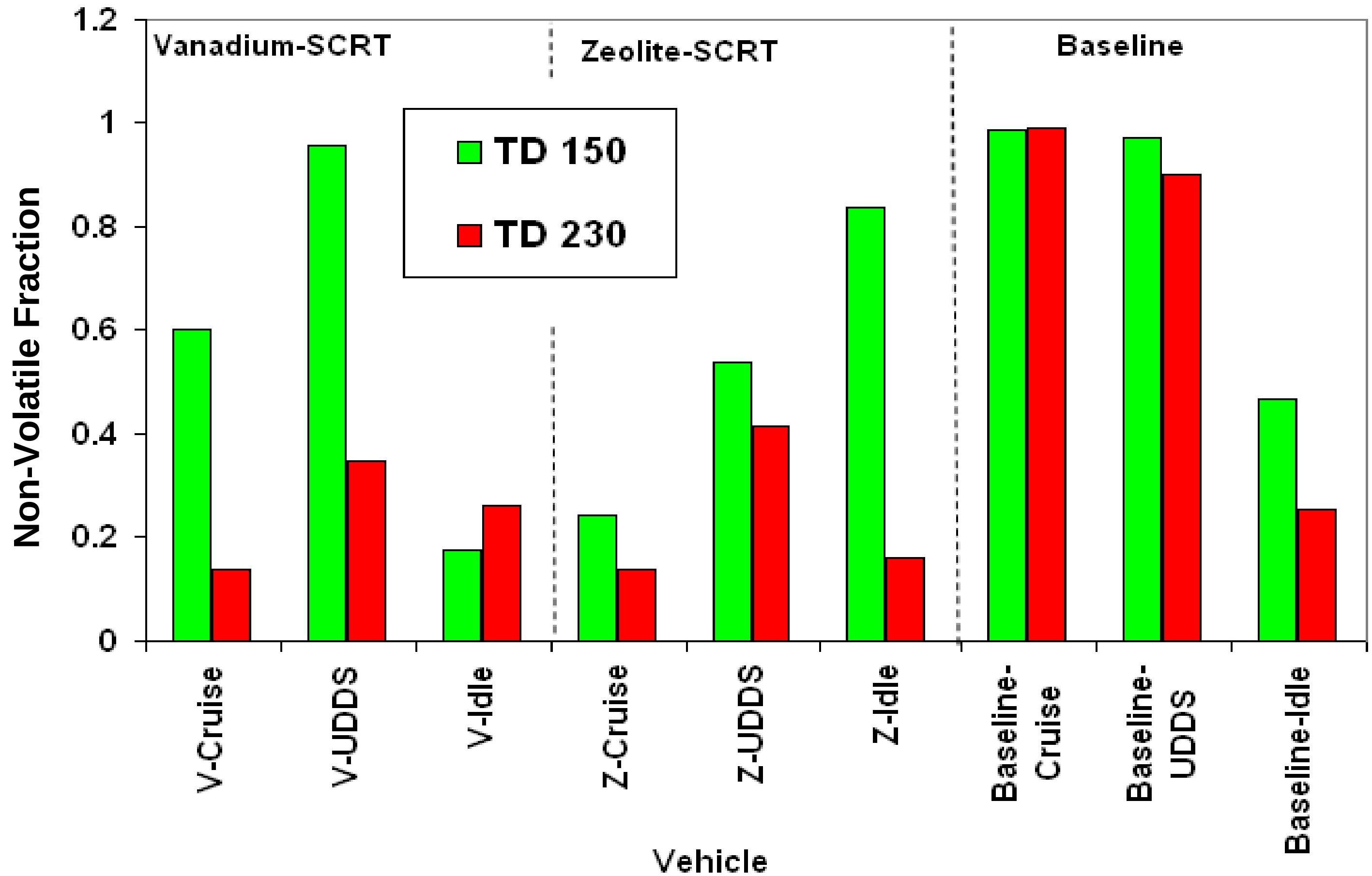
# Particle Volatility – Number Based

$$R = N_{Exhaust} / N_{TD}$$



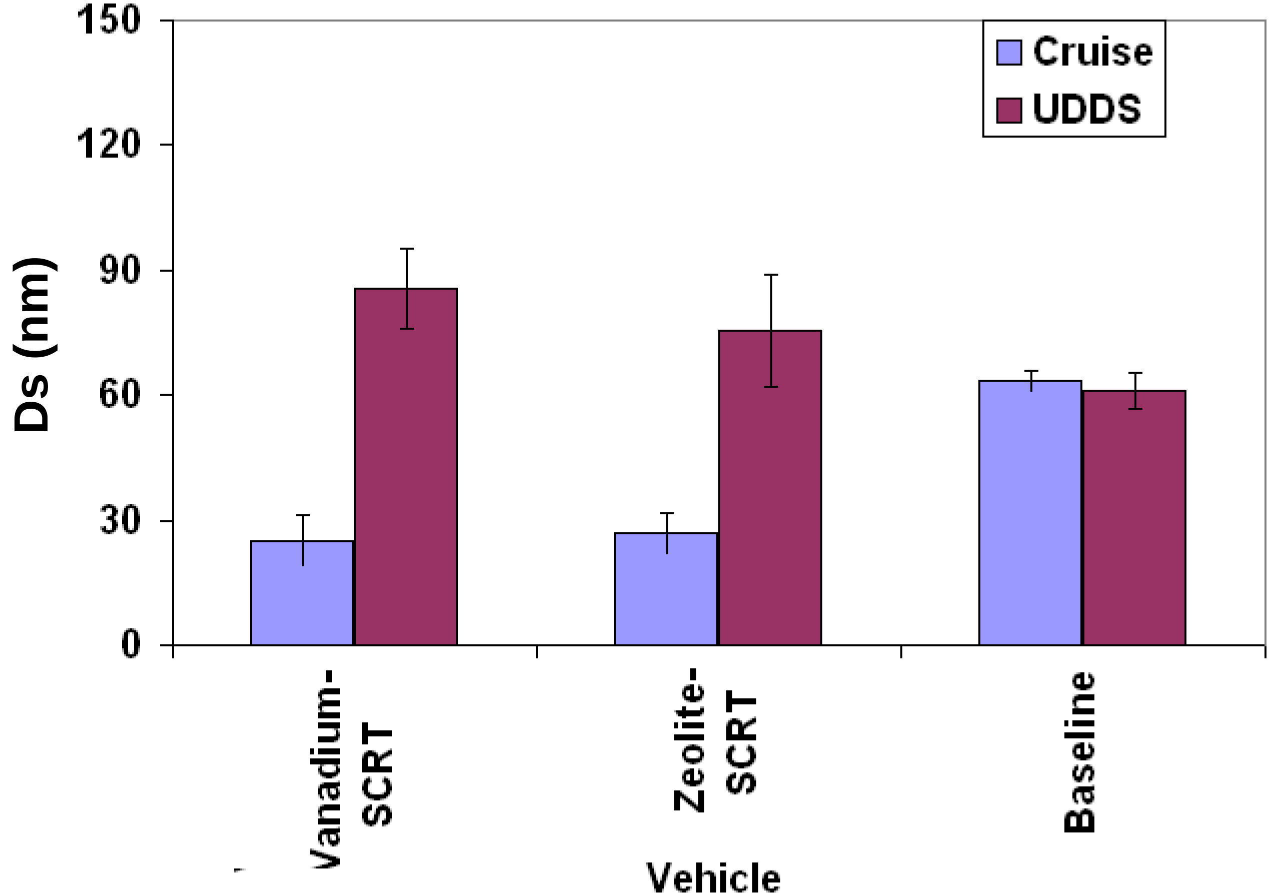

- Relatively larger fraction of particle from V-SCRT is volatile compared to Z-SCRT.
- This needs to be further confirmed by the chemical analysis from HiVol and thermodenuded filters.

# Particle Volatility – Mass Based $R = PM_{TD} / PM_{NM}$



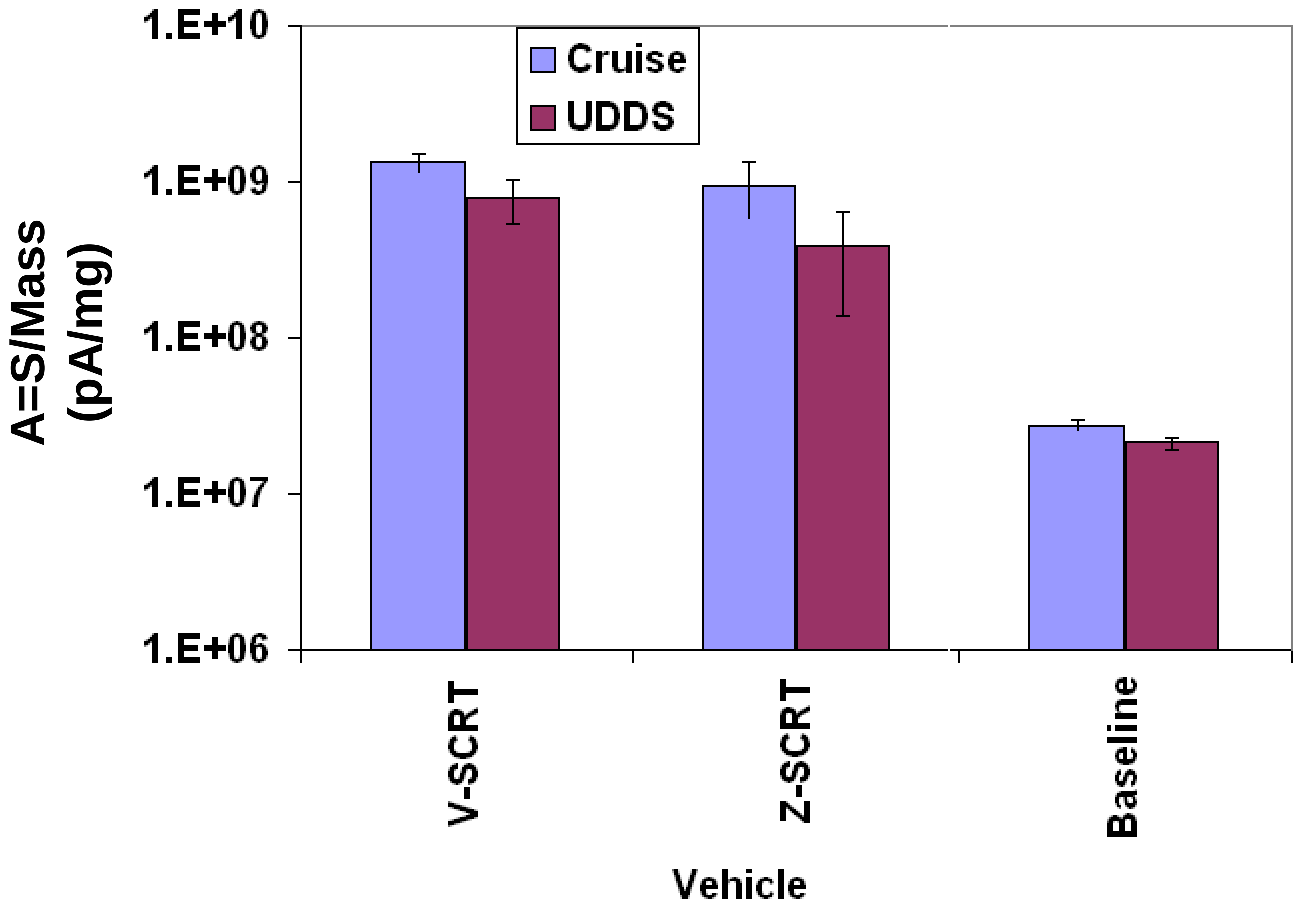

- **The Zeolite vehicle particle is comparatively more volatile on mass basis than number at T 150 ºC)**
- **At high T, V_SCRT and Z_SCRT is comparable**

# Surface Diameter

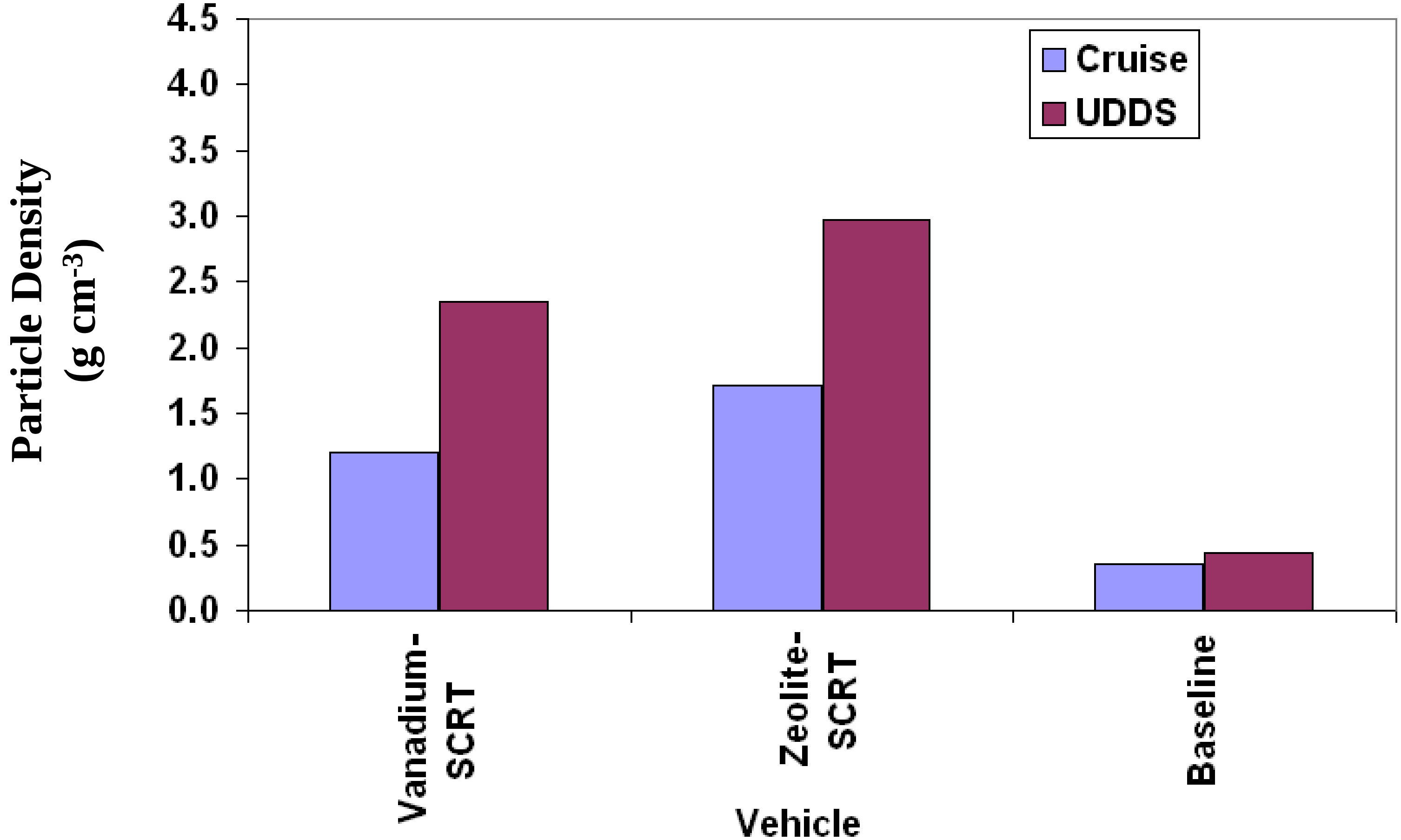



- **30nm for cruise mode of both SCRT systems, indicating nucleation mode particles**
- **Increased particle size for UDDS mode attributed to accumulation mode particles**

# Mass Specific Surface Concentration



# Particle Specific Density




- Lower value for baseline indicate fractal of the particles; around unity density implied more compact structure;
- Future chemical data to be integrated

# Conclusions

- The emission factors are remarkably low (<3 mg $km^{-1}$) for the newer fleet compared to the baseline vehicle (~300-400mg $km^{-1}$)
- Accumulation mode particles dominate for baseline vehicle without trap
- Nucleation mode particles dominate for both SCRT equipped vehicles during transient and cruise running cycles. However, the toxicity of the nucleation mode particles is under investigation.
- In term of number, R at 230 $^{o}$C is at least an order of magnitude higher than their counterparts at 150$^{o}$C, indicating complete disappearance of large chunk of particles within this temperature window.
- In term of mass, more than 90% of the particles completely **evaporate** at 230$^{o}$C during cruise mode. number
- The particle density more than unity for both SCRT vehicles implies that particles generated downstream of traps are structurally compact, contrast to those emitted from baseline vehicle which may be agglomerate.

# Thanks!

?

# Acknowledgements

**USC**

- Michael Geller
- Harish Phuleria
- Zhi Ning
- Vishal Verma
- Payam Pakbin
- Mohammad Arhami

**CARB**

- Ralph Rodas
- George Gatt
- Paul Rieger
- Oliver Chang
- Christine Maddox
- Keshav Sahay
- Jim Shears

## Sponsors

- California Air Resource Board (CARB)
- California Energy Commission (CEC)
- South Coast Air Quality Management District (SCAQMD)

# Data Processing

- Reduced variables (Ntziachristos et al., 2006)
  - $R = N_{Exhaust} / N_{TD}$ (1)

    where $N_{Exhaust}$ = Total dilution corrected DMS or EEPS number concentration at the CVS, $N_{TD}$ = number concentration measured by CPC after the thermodenuders. This is a measure of particle volatility in terms of number concentration.

  - $Ds\ (nm) = [I/ (0.0181*Nt *e*Q)]^{1/1.13}$ (2)

  - $A = S/ PM$ (3)

    where S = Active Surface Concentration, EAD signal in pico-amps (pA), PM = Total particle mass collected between 10nm and 2.5um nano-MOUDI stage. It is a measure of particle agglomeration.

  - $\rho = (PM_{NanoMOUDI}/ V_{EEEPS/DMS})$ (4)

    where, $PM_{NanoMOUDI}$ = Composite mass from 10nm to 2.5µm size ranges on the nano-MOUDI stages, $V_{EEEPS/DMS}$ = Total volume measured from DMS-EEPS or DMS size distribution assuming all the particles to be spherical.

# Temperature Profiles